HIGH FREQUENCY S-WAVE SCALING TO 500 KM

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ABSTRACT

A systematic effort at understanding high frequency ground motion of regional S and Lg phases is undertaken to develop stable, transportable methods for regional magnitude scale calibration. Aspects of the study are as follow:

a) an evaluation of the limitations of the coda normalization technique as a robust method of reducing effects of unknown source and site and instrument effects in determining the distance dependence of peak ground motion with distance,
b) the simultaneous determination of source, site and distance function,
c) an evaluation of the relation between the coda Q parameter and the frequency dependent peak motion distance function,
d) empirical determination of the relation between coda excitation and peak motion excitation, and
e) an attempt at modeling observations of peak motions in terms of wave propagation in crustal models, with the corresponding determination of the necessary detail of those models.

The results of studying ground motion in the 1 - 16 Hz frequency band in the New Madrid region of the central, and the Southern Great Basin regions of the United States show that significant regionally dependent crustal structure control of the distance dependence occurs in the 0-200 km range. Since this will affect the quantification of source properties from distant observations, one must worry about more than variations in average crustal Q. Crustal and upper mantle structure are also very important. Data processing of other data sets is beginning since the necessary software has been validated.

OBJECTIVE

This study addresses the problem of defining the scaling of high frequency S-wave ground motion with distance by using recordings of regional earthquakes and explosions. The methodology assumes as little as possible about the underlying functional form of the distance dependence because such assumptions may mask important, but unappreciated, affects of local earth structure.

The overall purpose of the study is to develop a methodology for defining a transportable seismic source size estimator for regional phases.

RESEARCH ACCOMPLISHED

In a region of low level seismicity, there is always a question of the scaling of ground motion with distance in order to correctly assign a magnitude to an event or to define proper ground motion levels for earthquake resistant design. In addition to low levels of observed ground motion, the task may be complicated by the lack of proper instrument calibration and unknown site effects. So how can one address unknown source, site and instrument effects?

Source - Site - Distance Separation

Peak ground motion of the S wave may be modeled as the separable effects of source, site and propagation

$$a(r,f) = Src_S(f)\, Site_S(f)\, d(r,f)$$

or after applying logarithms

$$PEAK = SRC_S(f) + SITE_S(f) + D(r,f)$$

For a large data set such that a) each site observes earthquakes at many distances, and b) all sites do not share a common character, separability works. In order to use the technique, constraints must be applied, e.g., forcing $D(r,f) = 0$ at some reference distance, and constraining some or all site terms, often by $\sum SITE_i = 0$. This last condition forces common site effects into all source terms.

If the data are not sufficient for this separation, then a coda normalization technique introduced by Aki (980) and used by Frankel *et al.* (1990) can be applied to obtain a first order estimate of D(r,f). The coda can be described by an rms (root mean square) function of lapse time as a function of source and site terms and a shape function depending upon the scattering environment. In the logarithmic domain, the separation of a bandpass filtered signal becomes:

$$RMS(f,t) = SRC_C(f) + SITE_C(f) + CODA(f,t)$$

If we assume that $SRC_C = a_1 SRC_S$ and $SITE_C = a_2 SITE_S$, then

$$D(r,f) = PEAK - RMS(f,t_{ref}) - CODA(f,t_{ref}) + K.$$

is a first order estimator of the $D(r,f)$ function if the assumptions are valid.

There are some important considerations based on recent work to keep in mind:

- It is now recognized (Atkinson and Boore, 1995) that actual ground motion scaling

in the 70 - 150 km range is not simple, because of changes in signal duration and amplitude due to S waves supercritically reflected at the crust mantle interface.

• Site effects can be very large and very significant. A recent study by Boore, Joyner and Fumal (1994) demonstrates a very strong correlation between observed peak ground motions and shallow S-wave velocity (30 m).

Data Processing

The data used are from regional seismic networks in the New Madrid and Southern Great Basin regions of the central and western United States, respectively. The are from similar 1-Hz seismometers digitized at 100 Hz using a 12-bit A/D. All observed data are deconvolved to yield vertical component ground velocity in the 0.5 - 30 Hz band. Next each observed trace is passed through band pass filters composed of a cascade of an 8 pole low pass and an 8 pole high pass Butterworth filter with respective corner frequencies of 1.414 f_n and 0.707 f_n, where the f_n are 1, 2, 3, 4, 6, 8, 10, 12, 14 and 16 Hz. For each filtered trace, the peak value is noted, and an RMS trace is computed using overlapping 5 second windows. In addition each RMS value has a flag indicating whether the value is prior to P, between P and S, after S, and into the coda (defined as twice the S wave travel time). The signal duration is estimated, and random process theory estimates of peak amplitudes are made.

Following this, the coda shape function, $CODA(f,t)$, is determined. Next and initial estimate of $D(r)$ is made, which is followed by an iterative regression for source, site and improved distance terms. The functional dependence of $CODA(f,t)$ and $D(r,f)$ is assumed to be piecewise linear, with a 2nd derivative smoothing constraint. For $D(r,f)$ distance nodes in the interpolation function are placed at 10, 15, 20, 30, 40, 50, 75, 90, 105, 120, 135, 150, 175, 200, 250, 300, 400 and 500 km. The time nodes for $CODA(f,t)$ are placed at 10, 20, 30, 40, 55, 70, 85, 105, 125, 145, 175, 210, 250, 290, and 330 seconds. Constraints that $D(40,f) = 0$, $CODA(f,10)$, $\sum SITE_S = 0$ and $\sum SITE_C = 0$ are applied.

Figure 1 shows the empirically determined coda shape for 2 Hz filtered data for the Southern Great Basin. Figure 2 shows the peak amplitude data for the same frequency. The coda normalization technique, top panel, yields a good estimate of the $D(r,f)$ term, which is very obvious at higher frequencies, which have fewer observations.

Figure 3 compares the $D(r,f)$ functions for the Southern Great Basin and New Madrid. Interpretation of the frequency dependence of each figure in terms of Q is not simple because of lack of knowledge of the underlying geometrical spreading function. However, regional differences are obvious in the levels of high frequency ground motion at large distances. In addition there appear to be differences in the ground motions in the 70 - 200 km, which are due to supercritical arrivals from the Moho and upper mantle.

The distance scaling for New Madrid differs significantly from a current model proposed for Eastern North America (Atkinson and Boore, 1995) at distances greater than 150 km. The New Madrid data requires a flattening of low frequency motion beyond this distance to 250 km whereas their model does not. This can only be understood in terms of differences in earth structure affecting the Lg. Figure 4 shows the an model, *modl.ham*, resulting from a waveform inversion of a broadband

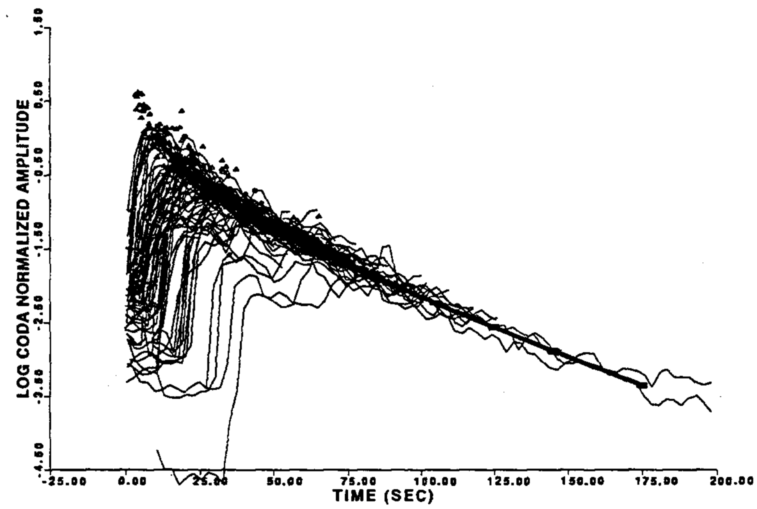

Fig. 1. Signal envelopes for 2 Hz filtered data. The shades of gray indicate signal prior to P, used for noise level, signal between P and S, signal between S and twice the travel time, and finally the signal in the stable coda. The heavy line is the coda shape function used in the coda normalization technique. The smaller symbols indicate the largest value of the RMS envelope, as well as the adjusted peak motion.

signal 175 km from a magnitude 4.4 Missouri earthquake of September 26, 1990. This earth model was required to align the high frequency S-arrivals in time, and also to improve the agreement in peak amplitudes. The waveform match requires a positive gradient in the upper mantle shear-wave velocity, which may be the explanation for larger high frequency amplitudes in the New Madrid region at this distance.

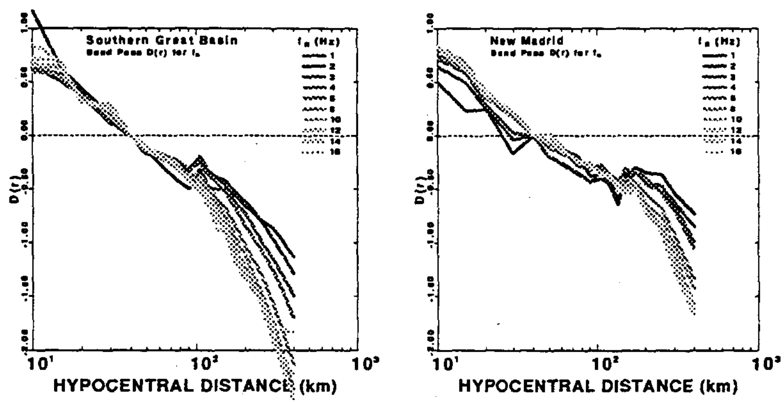

Fig. 3. Comparison of the empirically determined $D(r, f)$ terms for Southern Great Basin and New Madrid.

References

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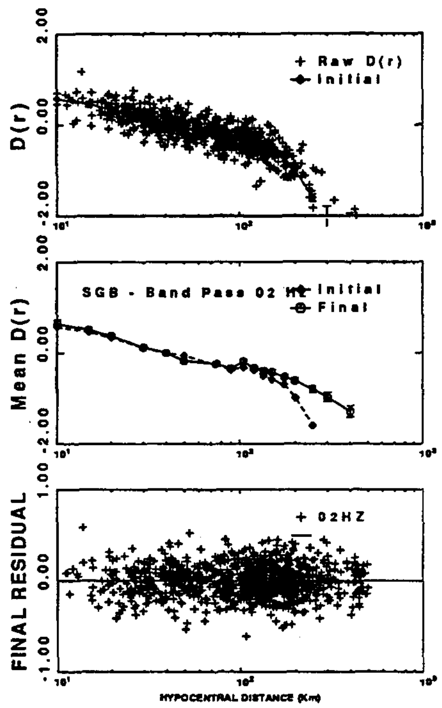

Fig. 2. Peak amplitudes and D(r,f). Bottom part. Residuals following the source, site and distance regression. The purpose is to demonstrate the independence of residual distribution with distance. Center panel, final distance dependence term (light gray) compared to initial estimate using coda normalization (darker with diamonds). Top panel, raw data of peak amplitude after coda normalization, together with the least square first estimate of D(r), shown more clearly in the center panel. Because of limited data lengths, the coda normalization could not be applied at large distances. The peak amplitude data filled in the large distance information.

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RECOMMENDATIONS AND FUTURE PLANS

A processing methodology has been developed for examining high frequency ground motions. The coda normalization technique is very useful. Initial data sets indicate the need for detailed knowledge of the crust-mantle transition to understand high-frequency shear-wave ground motion.

Future work will consider other regions, and will attempt to explain observations by combining high frequency ray theory, Q and random process theory. It is assumed that the velocity structure required to understand amplitude versus distance must be more detailed than that used for location.